Efficient Management of a High-Capacity Airborne Network of Commercial Aircraft

Keywords: airborne network, aviation, topology control, commercial aircraft, communication

Background

The Federal Aviation Administration (FAA) reports that on most days around 7,000 aircraft are constantly in the air over the United States. The United States passenger airlines alone invest more than $150 billion each year to operate this complex infrastructure, yet it is vastly underutilized. In addition to transporting passengers and cargo, high-flying nodes are uniquely positioned for a host of applications, including: communications, weather measurement and surveillance. However, no one has yet succeeded in utilizing this infrastructure to its full potential. To harness its power, the aircraft need to be connected together into a mesh network, and that airborne network needs to be connected to the Internet. This network would enable applications such as high-bandwidth on-board internet, digital pilot communications, coordinated take offs and landings, streaming weather and turbulence information between planes and to the ground, UAV coordination, and streaming live aerial footage. It may even be possible to broadcast Internet service from the aircraft, in a fashion similar to that proposed by Google's Loon project, but using an already existing infrastructure.

To achieve the high capacities and long ranges required of such a network, directional data links are recommended. These links have a narrow beamwidth and can be steered to point in specific directions, forming point-to-point connections between aircraft. The use of directional links requires that the topology of the network be explicitly managed. Further, the connections in the airborne network change frequently, motivating the need for specialized routing protocols which can manage routing tables while limiting overhead. One unique advantage of commercial air traffic, is that each aircraft has associated with it a flight plan, and the future position of nodes can be predicted with a high degree of accuracy.

Proposed Research

I propose a project to study the feasibility, utility, and efficacy of an airborne network "overlaid" on top of the existing commercial aviation system in the United Sates. The design of a topology control and routing protocol to manage a robust high-bandwidth airborne network among thousands of aircraft and a small number of ground stations will be studied. It is assumed the network will be implemented by using existing commercial aviation carriers (passenger and freight) in much the same way that the U.S. Postal Service (USPS) relies on such carriers for air-mail service. Thus, central to the architecture, and a point of novelty, is the reliable assumption that aircraft fly pre-determined point-to-point routes, according to a known flight plan.

To achieve high bandwidths (up to 10 Gbps point-to-point in clear conditions) and long ranges (at least 100 miles), with minimal power and interference, steerable directional RF antenna can be combined with Free Space Optical (FSO) transceivers. One unique challenge is that using these links will require explicit management of the network topology. A topology control protocol will be developed to utilize the expected future aircraft positions to adjust existing connections, and form new connections to replace those predicted to soon fail. Creative optimizations and organization will be used to ensure this can be done with limited overhead. In addition, a specialized routing protocol will be required to quickly respond to the frequent changes in the network topology, and route packets accordingly. Communication between the topology control and routing protocols will also reduce the management overhead.

Figure 1 shows an example of a topology connecting 2,291 aircraft in the NAS. This topology doesn't incorporate ground stations, but it is degree constrained such that no node has more than three connections. Each node is assumed to have a maximum range of approximately 120 nautical miles.

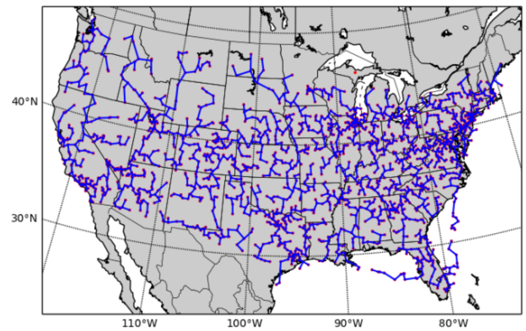

Figure 1 - A Degree Constrained Spanning Tree forming a network among 2,291 aircraft

Impact on CPS

Airborne Networking is a relatively new research area, and most of the work to date has been funded by the military and defense community. It is expected, however, that airborne networks will receive more attention in the near future as link technologies mature and become more economical. The proposed research involves several physical systems, including the ground stations, the steerable antennas, and the aircraft themselves. Solutions to sub-problems such as aligning actual flight paths with flight plans, and predicting future positions of aircraft, are widely applicable to other cyber physical systems. In addition, the algorithms developed for efficiently computing the topology of the network, will also apply to any system where a robust graph must be generated among degree constrained nodes.

This project involves a broad range of research areas, including: networking protocols, ad-hoc networking, aeronautics, air traffic management, and optimization, among others. It is anticipated that this project will benefit from and make contributions to the current state of the art in several domains. Some of the problems to be solved include: partitioning nodes into geographical subnets and associating them with a ground station and/or control node, aligning flight path information with the aircraft's flight plan, accurately predicting future aircraft locations, generating a topology graph which adheres to node restrictions and capabilities, optimizing the topology graph, determining coverage areas, efficiently communicating updates among nodes, and creatively managing routing tables. Combining research from these various areas will allow the development of a strong solution, and the advancement of the field of airborne networking. This unique cyber physical system will facilitate both transportation and communication, and contribute to the field of Cyber Physical Systems (CPS).